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The impacts of climate change according to the IPCC

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Abstract: I assessed five statements in the Summary for Policy Makers (SPM) of the Fifth Assessment Report (AR5) of Working Group II (WG2) of the Intergovernmental Panel on Climate Change (IPCC). The IPCC's assessment of the impacts of climate change on agriculture all but ignores human agency and human ingenuity. The statement in the SPM on violent conflict is much stronger than in the chapter and indeed the literature. AR5 ignores the literature on the impacts of climate change on cold-related mortality and morbidity. On poverty traps, WG2 reaches a conclusion that is not supported by the cited papers. The total impacts of climate change were assessed in four subsequent IPCC report. Although there are no statistically significant differences between the assessment periods in the underlying literature, the subsequent SPMs reach very different conclusions. In sum, the IPCC has yet to reach the quality that one would expect from a gold standard.

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) is a key part of climate research and policy. Every six years or so, the IPCC retains hundreds of researchers for a number of months to write authoritative reviews of the academic literature. These are used to guide research and funding priorities, and to judge new research. The Summary for Policy Makers (SPM) serves to create a common understanding of the climate problem in capitals around the world. IPCC reports should therefore be as sound as they can be – but unfortunately, although the IPCC is sometimes said to set the gold standard (Nature, 2010b), they are not always, as discussed below.

Much has been written about how the IPCC assesses the literature (Alexander, 2007, Gilland, 2007, Henderson, 2007, Hulme, 2010, Hulme and Mahony, 2010, Kintisch, 2010, Laframboise, 2011, McKitrick, 2010, Nature, 2010a, Schiermeier, 2010, Scientist, 2010, Nishioka, 2008, Oppenheimer et al., 2007, PBL, 2010, Peiser, 2007, Rothman et al., 2009, Shapiro et al., 2010, Solomon and Manning, 2008, Tol, 2011, Tonn, 2007, van der Sluijs et al., 2010, Wynne, 2010, Zillman, 2007, Beck et al., 2014, Skoglund and Jensen, 2013, Nicholls and Seneviratne, 2013, Jones, 2013, Freudenburg and Muselli, 2013, Brysse et al., 2013, Betz, 2013), and also about the confidence expressed in its conclusions (Budescu et al., 2012, Budescu et al., 2009, Curry and Webster, 2013, Moss and Schneider, 2000, Narita, 2012, Risbey and Kandlikar, 2007, Smithson et al., 2012, van der Sluijs, 2012, Budescu et al., 2014, Harris et al., 2013, Betz, 2007). I do not revisit that general debate here, but rather focus on the Fifth Assessment Report (AR5) of Working Group II (WG2) of the IPCC.

The WG2 report's outline, agreed by committee, was full of overlaps and holes, and did not reflect the state of knowledge. Authors were invited to devote many pages to scant literatures while cramming rich literatures into too little space. Authors were selected on many grounds, their expertise not necessarily being the overriding criterion. Some world-class experts ended up in chapters that were far from their domain of knowledge. And because the outline was so chaotic, much time was lost in delineating chapters.

In the IPCC process, deadlines trump quality control. It matters more that the chapter is finished in time than that the chapter is good. Referees volunteer to review the report on their pet interests. Review editors do not seek input from specific experts. Parts of the report are therefore never seen by field experts.

IPCC chapters are summaries of the literature. The chapters are further condensed in the Summary for Policy Makers (SPM), the Synthesis Report, its SPM, the press release, and the newspaper headlines. Chapters compete for such attention by dramatizing their findings.

Some argue that the IPCC process is needed for policy buy-in, but even that is not as it seems. For instance, negotiations about the Summary for Policy Makers (SPM) are exhausting so that small country delegations are de facto excluded from crucial last-minute discussions.

You may argue that climate research would be better off without the IPCC. The IPCC, however, meets a demand. Climate policy responds to a projected future. It is built on predictions and assessments of what the world would be like if we reduce greenhouse gas emissions by a little or a lot. Climacrats' jobs depend on the regular reassurance that climate change is real, human-made, and a problem that can only be solved by employing large numbers of civil servants, consultants, and academics. Few countries – perhaps only the USA – can mount the breadth of expertise needed to do justice to an issue as complicated as climate change and policy. Few alternatives to the IPCC would garner the credibility required to justify the vast public expense on climate policy. If the IPCC would not be there, it would be invented straightaway. Elsewhere, I have argued that the IPCC has a natural monopoly on climate-knowledge-for-policy and that it should therefore be strictly regulated (Tol, 2011).

In the remainder of this paper, I sample topics from IPCC WG2 AR5 to illustrate some of the points above. I have not read the report cover to cover, and if I had it would be impossible to discuss everything in the short space of a journal article. Instead, I'll review five topics. Four are grouped in Section 2: agriculture, violent conflict, health, poverty traps. I contrast the summary statements with the underlying chapter, and the chapter with the underlying literature.

The summary statements of the Intergovernmental Panel on Climate Change (IPCC) attract extraordinary attention in policy and research. It is not always clear how the IPCC arrived at these statements and the confidence expressed. I here consider one particular case: The total economic impact of climate change. In Section 3, I review how the literature developed over time, consistently apply the same statistical method to the data available at the time of writing the last four assessment reports, and compare the results to what was written in those reports.

Section 4 concludes.

2. Sectorial impacts

2.1. Agriculture

The SPM of the Synthesis Report (Pachauri et al., 2014) concludes that "[c]limate change is projected to undermine food security […] [f]or wheat, rice and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2°C or more above late 20th century levels, although individual locations may benefit […] [g]lobal temperature increases of ~4°C or more above late 20th century levels, combined with increasing food demand, would pose large risks to food security globally". The SPM of the WG2 report has very similar language (Field and Canziani, 2014). Chapter 7 adds that "[t]here remains limited quantitative understanding of how non-production elements of food security will be affected, and of the adaptation possibilities in these domains" (Porter et al., 2014). In other words, the dramatic statements in the SPM are mostly about crop yields rather than about food. Ignoring human agency (Auffhammer and Schlenker, 2014, Hertel and Lobell, 2014), the IPCC has a peculiar perspective on food growing.

The SPM of the WG2 report reproduces a graph (7.5) from the underlying chapter, showing the fraction of negative and positive yield projections "for adaptation and no-adaptation cases combined". Figure 7.4 does split estimates with and without adaptation, although it would have been helpful to restrict the sample to studies that report a crop yield estimate both with and without adaptation.[1] Several country delegates asked Figure 7.5 to be replaced in the SPM by Figure 7.4. One even cited a training session organized by the IPCC, in which he had been taught that impact estimates with adaptation are more informative and relevant than impact estimates without.

Figure 7.7 shows that "[e]ach additional decade of climate change is expected to reduce mean yields by roughly 1%". This is compared to a projected 14% per decade increase in global food demand. Chapter 7 downplays past technological progress in agriculture, which pushed up yields (Rudel et al., 2009). Future technological advances are similarly de-emphasized. Current inefficiencies in agricultural production are not mentioned at all, even though in

[1] There is no supplementary material to Chapter 7, so I cannot redraw these graphs.

some parts of the world crop yields would increase tenfold if farmers would use state-of-the-art methods (Mueller et al., 2012). Ignoring human ingenuity, Chapter 7 paints an overly bleak picture of the future of agriculture.

2.2. Violent conflict

The SPM of the Synthesis Report (Pachauri et al., 2014), the Synthesis Report itself, and the SPM of the WG2 report (Field and Canziani, 2014) state that “[c]limate change can indirectly increase risks of violent conflicts by amplifying well-documented drivers of these conflicts such as poverty and economic shocks”. This statement is linked back to Chapters 12, 13 and 19. Chapter 13 writes, in passing, about the effects of violent conflict on vulnerability to climate change, but not about the impact of climate change on violent conflict (Olsson et al., 2014).

Chapter 12 is more circumspect: “Some of the factors that increase the risk of violent conflict within states are sensitive to climate change […]. Although there is little agreement about direct causality, low per capita incomes, economic contraction, and inconsistent state institutions are associated with the incidence of violence […]. These factors can be sensitive to climate change and variability” (Adger et al., 2014).

Chapter 19 writes, more stridently, that “[t]he effect of climate change on conflict and insecurity is an emergent risk because factors such as poverty and economic shocks that are associated with a higher risk of violent conflict are themselves sensitive to climate change” (Oppenheimer et al., 2014). However, the statement in Chapter 19 is less pronounced than the statement in the SPM: The Chapter notes a sensitivity but the SPM notes a direction of change.

On the direct effect of climate change on conflict, Chapter 12 writes that “[t]he evidence on the effect of climate change and variability on violence is contested“, whereas Chapter 19 notes that “[i]n numerous statistical studies, the influence of climate variability on violent conflict is large in magnitude”. The direct effect was omitted from the SPM, and I would argue that Chapter 12 better reflects the literature (Buhaug et al., 2014).

Chapter 12 was written by field experts, while Chapter 19 was written by generalists. Instead of siding with the cautious experts, the SPM exaggerated the assessment of the non-specialists. One explanation is that Chapter 12 vetoed a statement on the direct impact of climate change on conflict, in return for which Chapter 19 was allowed to sex up its own judgement.

2.3. Human health

The Synthesis Report and the SPM of WG2 mention heat stress and its effect on human health, but omit cold stress. Chapter 11 discusses health impacts in greater detail (Buhaug et al., 2014). It notes that “the association between hot days […] and increases in mortality is very robust” but that “[t]he rise in minimum temperatures may have contributed to a decline in deaths associated with cold spells”. The difference in tone is striking, as discerning the effect of weather from its confounders is as hard for summer deaths as it is for winter deaths. Section 11.4.1.1 discusses the mechanisms by which extreme temperature affects human health. The focus is on heat. Mild winters are mentioned only because they increase the vulnerability to extreme heat in the following summer. The authors omit that mild winters thus prolong lives by some six months.

Chapter 11 writes that "the impacts on health of more frequent heat extremes greatly outweigh benefits of fewer cold days", citing two studies (Ebi and Mills, 2013, Kinney et al., 2012) that only consider cold deaths. Chapter 11 does not cite studies that consider both (Åström et al., 2013, Bell, 2013, Błazejczyk et al., 2013, Chen et al., 2013, El-Fadel and Ghanimeh, 2013, Guo et al., 2013, Li et al., 2013, Madrigano et al., 2013, Oudin Åström et al., 2013, Shaposhnikov et al., 2013, Xu et al., 2013, Zanobetti et al., 2013). These studies, published while Chapter 11 was being written, show a more nuanced story (Deschenes, 2014): In some parts of the world, the reduction in cold-related mortality outweighs the increase in heat-related mortality; in other parts of the world, it is the other way around. The conclusion of Chapter 11 is not supported by the literature.

2.4. Poverty traps

Chapter 13 of IPCC WG2 AR5 finds "[a] predicted increase in the number of urban poor […] a large number may […] find themselves in a poverty trap" (Olsson et al., 2014). This morphs into "climate change impacts are projected to […] prolong existing and create new poverty traps" in the SPM (Field and Canziani, 2014) and in the Synthesis Report (Pachauri et al., 2014). If true, this would be a most important finding: The welfare loss of being trapped in poverty, as opposed to growing steadily, is rather large.

Chapter 13 cites two studies in support. One (Ahmed et al., 2009) is based on a *static* computable general equilibrium and therefore silent on poverty traps, an inherently *dynamic* concept (Carter and Barrett, 2006). Indeed, the Ahmed paper does not use the words "poverty trap" at all. The other paper (Hertel and Rosch, 2010) is a survey. It discusses the evidence on extreme-weather-induced poverty traps, but warns that this does not carry over climate change because of adaptation. (Dell et al., 2014) similarly warn that the impacts of weather should not be confused with the impacts of climate change. The IPCC drew a strong conclusion, based on two studies only, neither of which actually supports the conclusion.

3. Economic impacts

3.1. Data

There are 19 papers that estimate the impacts of climate change on *global* welfare, listed in Table 1. The 21 estimates are based on different methods. Nordhaus (1994a) surveyed a limited number of experts, although at that time few had published on the subjects. Other papers estimated the "physical effects" of climate change, estimated their price, multiplied the two and aggregated across impacts (Nordhaus, 1994b, Nordhaus, 2008, Fankhauser, 1994, Fankhauser, 1995, Tol, 1995, Tol, 2002a, Tol, 2002b). Other researchers used physical impact estimates as shocks to a computable general equilibrium model (Bosello et al., 2012, Roson and van der Mensbrugghe, 2012). In yet other studies, spatial variations in prices and expenditures (Maddison, 2003, Mendelsohn et al., 2000b, Mendelsohn et al., 2000a, Nordhaus, 2006) or happiness (Rehdanz and Maddison, 2005, Maddison and Rehdanz, 2011) are used to estimate the impact of climate.

These studies broadly agree in three areas (Tol, 2009). First, the effect of a global warming of 2.5˚C on the current economy is relatively small; it is equivalent to losing a few percent of income. In other words, the impact of a century of climate change is roughly the same as losing a year's growth.

Second, the initial impacts of climate change are probably positive. These benefits are followed by losses as temperatures increase further. See Figure 1. The initial benefits arise partly from CO_2 fertilization, which affects everyone but disproportionally poorer people. Reduced heating costs and cold-related health problems are benefits to temperate zones in particular. However, as the initial warming can no longer be avoided, these benefits are sunk, and should not affect decisions about emission reduction.

Third, the uncertainty is large and right-skewed. Undesirable surprises are more likely than desirable surprises of equal size. This is due to the nature of the problem. The climate sensitivity – the equilibrium warming in response to a doubling of the atmospheric concentration of carbon dioxide – is bounded from below by the laws of physics; however, it is hard to put an upper bound on its value. Impact functions are nonlinear. For instance, the benefits of reduced winter heating are capped by current spending, but the costs of increased summer cooling are unbounded. Furthermore, while it is relatively easy to paint disastrous pictures of the impacts of climate change – rapid sea level rise in the Bay of Bengal leading to mass migration and nuclear war – it is difficult to imagine that climate change would make the world prosperous and peaceful.

The uncertainties about the impacts are compounded by extrapolation (Tol, 2012). Most estimates are for 3°C of global warming or less, but climate change may well go beyond that. These uncertainties are, of course, an argument for more stringent climate policy.

3.2. Method

I use kernel regression to estimate the relationship between climate change and total economic impact. As there are few observations only, my interpretation is closer to the mixtures of Laplace (1814) than to the kernels of Rosenblatt (1956) and (Parzen, 1962). I use a bivariate normal kernel (Nadaraya, 1964, Watson, 1964); and use the Silverman (1986) rule-of-thumb to set the bandwidth equal to $h=1.06\Sigma^{-0.5}n^{-0.2}$, where Σ is the sample covariance matrix and n is the sample size. I limit support of the kernel to the range from the lowest observation minus four times the standard deviation (as defined by the Silverman rule) to the highest observation plus four times the standard deviation.

Some of the estimates in Table 1 are reported along with some indication of the confidence in that estimate. Different studies use different notions of "confidence", and as most studies omit this altogether, I decided to only use the reported best estimates. This simplifies the analysis, but leads to an overconfident result.

Note that kernel regression is defined for any number of observations. More observations typically support sharper inference, but this is true for parametric and non-parametric methods alike.

Standard kernel regression (Takezawa, 2006) does not impose any functional form on the impact function. Indeed, that is one of its main strengths. However, by construction, zero climate change has zero impact. I therefore constrain the kernel regression to go through the origin by adding a 22nd observation with $h^*=h/10$. The division by ten is ad hoc, chosen by experimentation. If the bandwidth of the restriction is too large, it is not met in expectation; if the bandwidth is too small, the restriction holds only locally and the kernel function loses its smoothness. See Tol (2015) for more detail.

Typical kernel regression is focused on the conditional mean, in this case, the expected impact conditional on (as a function of) the change in the global mean surface air temperature. The conditional mean is, of course, the mean of the conditional distribution. The kernel density estimate of the conditional distribution can be interpreted as a Laplacean mixture (Laplace, 1814). I here use the entire conditional distribution, as that reveals the confidence bounds not about the mean but rather about the parameter of interest.

3.4. Results

Figure 1 shows the restricted Nadaraya-Watson kernel regression and its 95% confidence interval for the studies published before the Second Assessment Report, the Third, the Fourth and the Fifth, respectively. Before AR4, estimates of the impact of were limited to warming of 2.5°C and 3.0°C. The kernel regression is therefore valid only for a limited range of climatic changes. This range shrinks between AR2 and AR3 as the number of observations rises from 4 to 9, and the standard deviations shrink accordingly.

In all four cases, the expected impacts cross zero somewhere between 1°C and 2°C of global warming – suggesting net positive impacts for milder warming for AR2 and AR3, and showing such for AR4 and AR5. Impacts get progressively more negative for greater warming, but only become statistically significantly different from zero somewhere between 3°C and 4°C.

Figure 2 repeats some of the information in Figure 1, but reorganized so as facilitate comparisons. For 1.6°C of warming, there is no statistically significant difference between the assessment reports. The same is true for the impacts of 2.5°C and 3.5°C of warming. Furthermore, there is no statistically significant difference between the impacts of 1.6°C and 3.5°C of warming for any of the four assessment reports.

3.5. IPCC

The above assessment of our knowledge of the impact of climate change reveals that we knew little in 1995 and have not learned a whole lot since. One could argue that there are too few observations to apply any statistical method, let alone to test for different results in different subsamples of the data. However, such a critique does not just apply to the current paper – I find no statistically significant difference, even though the method as applied is overconfident – but to any assessment, whether statistical as above or qualitative as in the IPCC. So what did the successive IPCC assessment reports write?

The technical summaries report the following:

AR2 "damages for developed countries […] between 1% and 2% of GNP for a 2xCO2 climate […] damage in different developing regions range from a minimum of 2% of GNP to a maximum of 9%" (Pearce et al., 1996)

AR3 "with a small [2°C] temperature increase, there is medium confidence that aggregate market sector impacts would amount to plus or minus a few percent of world gross domestic product (GDP), and there is low confidence that aggregate nonmarket impacts would be negative. […] Most studies of the aggregate impacts find that there are net damages at the global scale beyond a medium temperature increase [3°] and that damages increase from there with further temperature increases." (Smith et al., 2001)

AR4 "[t]here is some evidence that initial net market benefits from climate change will peak at a lower magnitude and sooner that was assumed for [AR3], and it is likely that there will be higher damages for larger magnitudes of global mean temperature increases than was estimated in [AR3]" (Schneider et al., 2007)

AR5 “Globally aggregated economic impacts of global warming are a small fraction of income up until 3°C [10.9.2, *medium evidence*, *high agreement*]. A global mean average temperature rise of 2.5C may lead to global aggregated economic losses between 0.2 and 2.0% of income (*medium evidence, medium agreement*) and losses increase with greater warming. Little is known about aggregate economics impacts above 3°C.” (Arent et al., 2014)

Compared to the state of knowledge at the time, AR2 was overconfident. AR3 more accurately reflected the uncertainties, but peculiarly suggested that the best guess at the time was zero impact with a symmetric confidence interval. AR4 stresses the differences with AR3, which are in fact insignificant. If anything, AR4 should have been more optimistic about the impact of larger warming. AR5 omits the initial benefits, shows the 67% confidence interval (rather than the 95% one as in Figures 1 and 2), and admits to ignorance about the impacts of larger climate change.

The summaries for policy makers (SPM) have the following language:

AR2 “aggregate estimates [of total damages from 2-3˚C warming] tend to be a few percent of world GDP, with, in general, considerably higher estimates of damage to developing countries” (Bruce et al., 1996)

AR3 “when aggregated to a global scale, world gross domestic product (GDP) would change by ± a few percent for global mean temperature increases of up to a few ˚C (*low confidence* [5-33]) and increasing net losses would result for larger increases in temperature (*medium confidence* [33-67])” (McCarthy et al., 2001)

AR4 “[f]or increase in global mean temperature of less that 1-3˚C above 1990 levels, some impacts are projected to produce benefits in some places and some sectors, and produce costs in other places and other sectors. It is very likely that all regions will experience either declines in net benefits or increases in net costs for increases in temperature greater than about 2-3˚C […] global mean losses could be 1-5% GDP for 4˚C warming” (Parry et al., 2007)

AR5 “With these recognized limitations, the incomplete estimates of global annual economic losses for additional temperature increases of ~2°C are between 0.2 and 2.0% of income (±1 standard deviation around the mean) (*medium evidence, medium agreement*). Losses are *more likely than not* to be greater, rather than smaller, than this range (*limited evidence, high agreement*). Losses accelerate with greater warming (*limited evidence, high agreement*), but few quantitative estimates have been completed for additional warming around 3°C or above.” (Field and Canziani, 2014)

Compared to the technical summary, the SPM of AR2 softens the quantitative information. The first clause in the SPM of AR3 is garbled: Welfare impacts are presented as changes in the level of economic activity. The range of impacts is identified as the 5-33% confidence interval, suggesting that most of the probability mass lies outside a few percent. Because AR3 seems to write about impacts (rather than damages), this would imply that there is 67% probability of benefits greater than “a few percent”. The second clause in AR3 is a shortened version of the technical summary. The SPM of AR4 is more circumspect about the net benefits of initial climate change than the technical summary, and has more quantified information about the net damages – including for a 4˚C warming, for which no estimates had been published at the time (cf. Table 1). The SPM of AR5 starts with caveats, removes the quantitative information for warming beyond 2.5°C[2] (although it does sketch the shape of the impact curve), and adds that the uncertainty is asymmetric.

The comparison of the language in the technical summaries to a standardized analysis of the state of knowledge suggests that there is a lack of consistency in IPCC assessments. This is particularly pronounced when comparing successive reports: Although there has been little advance in quantified knowledge over the 19 year period between AR2 and AR5, the IPCC suggests otherwise. Where the technical summaries have difficulty in consistently capturing what is known, the summaries for policy makers add further distortions – in one case changing the interpretation (SPM AR3) and in another adding unsupported statements (SPM AR4).

4. Discussion and conclusion

I briefly reviewed four statements from the Fifth Assessment Report of Working Group II of the Intergovernmental Panel on Climate Change; and one statement in more detail. In agriculture, the IPCC was unwarrantedly pessimistic by downplaying adaptation and technological change. While to a degree unpredictable and hard to model, assuming that farmers do not adapt and that methods and crops will not improve is most certainly wrong. In health, the IPCC all but ignored a substantial literature on the impact of climate change on cold-related mortality. For violent conflict, the IPCC highlighted a message in the Summary for Policy Makers that is not supported by the relevant chapters, let alone the literature. For poverty traps, the chapter misrepresents the literature, and the SPM underlines this. All in all, quality control remains a real issue in the IPCC.

I gathered estimates of the total economic impact of climate change, and split the sample according to the timing of the four latest assessment reports of the IPCC. I applied the same statistical method to the subsamples, and found that, although the number of estimates increased over time, the information contained in those estimates added little to the stock of knowledge. The technical summaries of the successive assessment reports do not consistently reflect the underlying information, and the summaries for policy makers further distort what is known.

The first four case studies all show a bias towards exaggerating the impacts of climate change. IPCC statements on the total economic impact are heavily caveated, although much better founded that the IPCC statements on, say, poverty traps, which are not caveated at all.

Are these five cases representative? Are there issues with other statements in the SPM too? Do Working Groups I and III have problems that are similar to those in WG2? I do not know. As I wrote above, I have not read AR5 front to back, let alone conduced a forensic examination of the entire report. My selective reading was guided by the four horsemen of the apocalypse – famine, war, pestilence, and death – and my long-standing interest in the total economic impact of climate change. So, my selection is orthogonal to quality, and one would expect that further digging would uncover other issues. I would encourage further investigation of the IPCC reports.

[2] The SPM of AR5 refers to temperature increases relative to "recent times" which is 0.6°C above pre-industrial.

Table 1. Estimates of the welfare loss due to climate change (as equivalent income loss in percent); estimates of the uncertainty are given in bracket as standard deviations or 95% confidence intervals.

Study	Warming (˚C)	Impact (%GDP)
AR2		
(Nordhaus, 1994b)	3.0	-1.3
(Nordhaus, 1994a)	3.0	-3.6 (-30.0 to 0.0)
(Fankhauser, 1995)	2.5	-1.4
(Tol, 1995)	2.5	-1.9
AR3		
(Nordhaus and Yang, 1996) [a]	2.5	-1.7
(Plambeck and Hope, 1996)[a]	2.5	-2.5 (-11.4 to -0.5)
(Mendelsohn et al., 2000a) [b]	2.5	0.0[b] 0.1[b]
(Nordhaus and Boyer, 2000)	2.5	-1.5
AR4		
(Tol, 2002a)	1.0	2.3 (1.0)
(Maddison, 2003)[a,c]	2.5	-0.1
(Rehdanz and Maddison, 2005)[a]	1.0	-0.4
(Hope, 2006) [a,d]	2.5	-0.9 (-2.7 to 0.0)
(Nordhaus, 2006)	3.0	-0.9 (0.1) -1.1 (0.1)
AR5		
(Nordhaus, 2008)	3.0	-2.6
(Maddison and Rehdanz, 2011) [a]	3.2	-12.4
(Bosello et al., 2012)	1.9	-0.5
(Roson and van der Mensbrugghe, 2012)	2.9 5.4	-2.1 -6.1

[a] Note that the global results were aggregated by the current author.

[b] The top estimate is for the “experimental” model, the bottom estimate for the “cross-sectional” model. Mendelsohn et al. only include market impacts. Note that the IPCC reports the increase in the population-weighted mean temperature; for consistency with the other estimates, we here use the area-weighted mean temperature.

[c] Maddison only considers non-market impacts on households.

[d] The numbers used by Hope are averages of previous estimates by (Fankhauser, 1995) and (Tol, 2002a); (Stern et al., 2006) adopt the work of Hope.

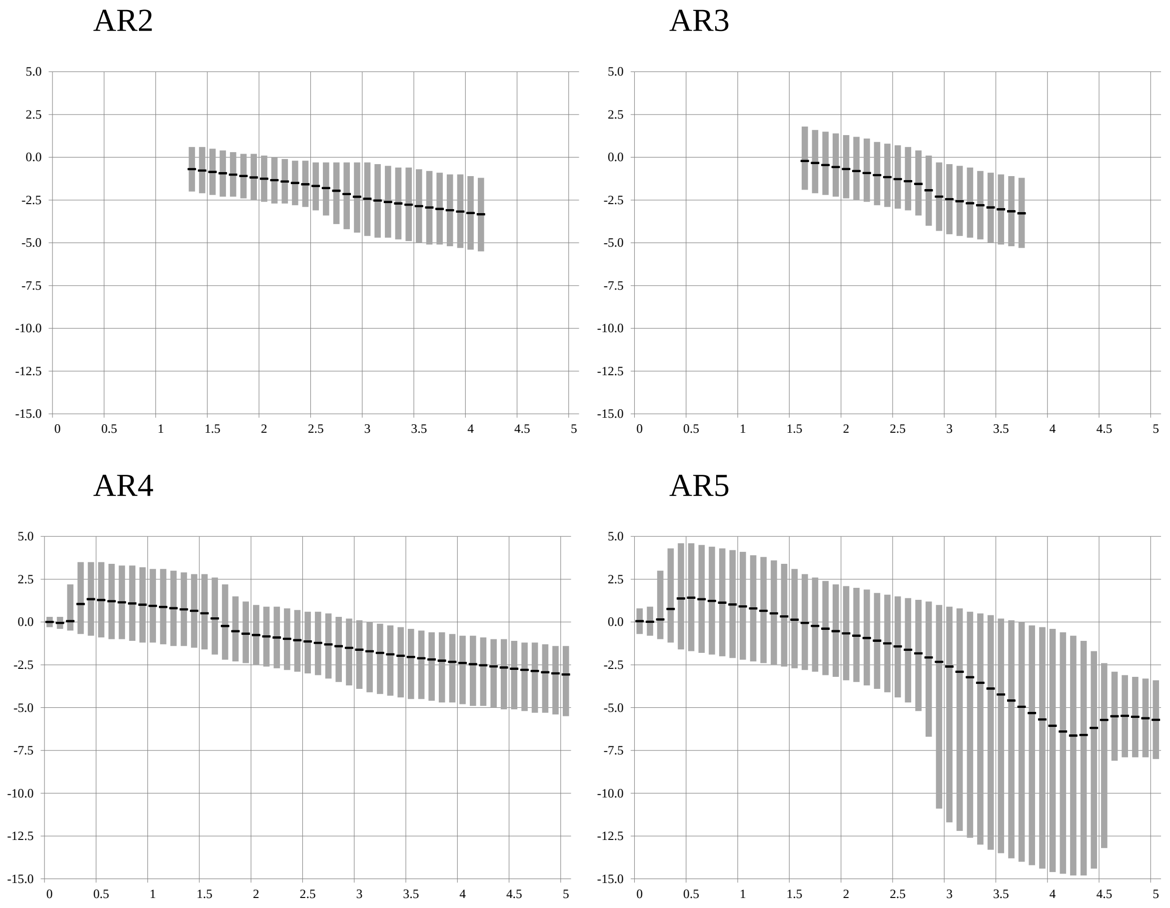

Figure 1. Restricted Nadaraya-Watson kernel estimates of the impact (welfare-equivalent income loss, percent, vertical axes) of climate change (increase in the global mean surface air temperature since preindustrial times, degree Celsius, horizontal axes) for studies published before the Second (AR2), Third (AR3), Fourth (AR4) and Fifth (AR5) assessment report of the Intergovernmental Panel on Climate Change.

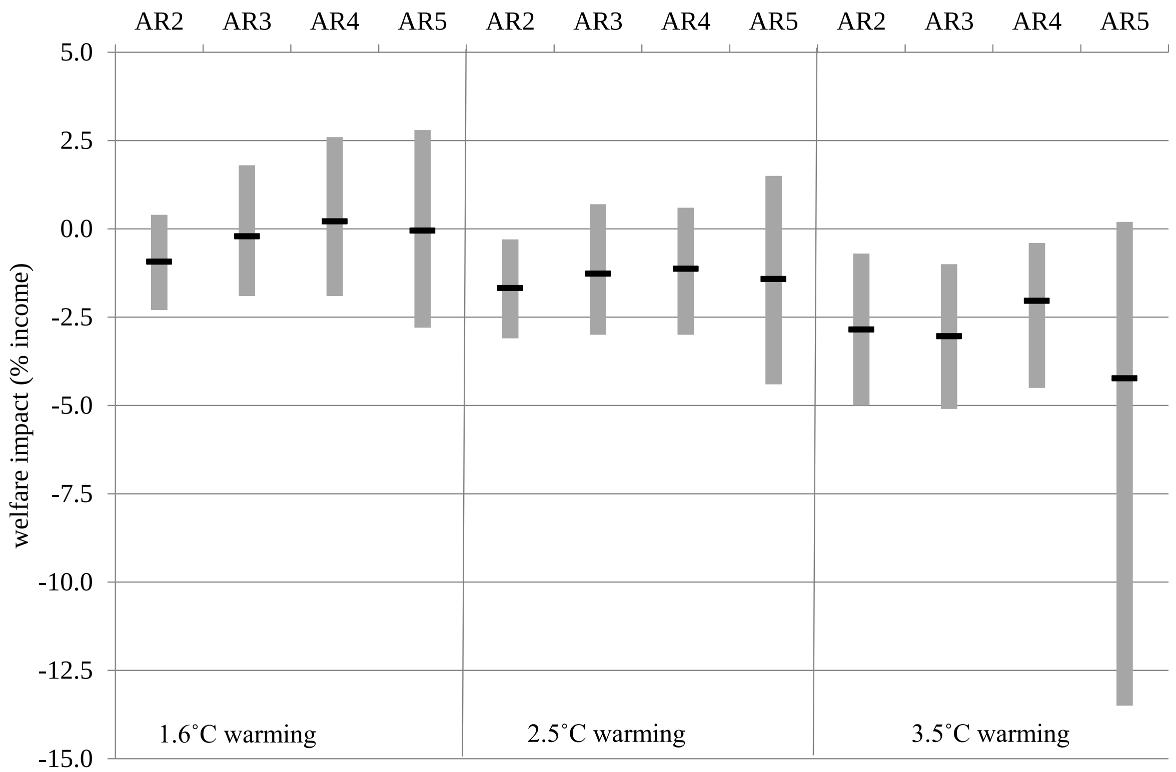

Figure 2. Restricted Nadaraya-Watson kernel estimates of the impact of climate change

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